SENSING DEVICE FOR DETERMINING A RAIN RATE

BACKGROUND OF THE INVENTION

1. Field of the Invention

[0001] The subject invention generally relates to a sensing device for determining a rain rate on a surface. More specifically, the subject invention relates to a sensing device for determining the rain rate of raindrops striking a glazing (i.e. windshield, rear window, side windows, etc.) of a vehicle such that a wiper is activated to remove the raindrops from the glazing.

2. Description of the Related Art

[0002] Various sensing devices for detecting raindrops are known in the prior art. One example of such a device is disclosed in United States Patent No. 5,119,002. Specifically, the '002 patent discloses a device which includes a piezoelectric vibration sensor, an amplifier, a processor, a motor, a wiper blade, and a windshield. The piezoelectric vibration sensor and the amplifier are disposed within a raindrop detector. The raindrop detector is placed on the hood of a vehicle. When raindrops strike the raindrop detector, vibrations are produced. The piezoelectric vibration sensor generates a signal corresponding to these raindrops. The amplifier increases an amplitude of the signal. The processor calculates an intermittent period based on the intensity of the signal and uses that intermittent period to operate the motor. The motor in turn moves the wiper blade.

[0003] The '002 patent does not disclose an analog-to-digital converter (ADC) to convert the analog signal into digital values. An ADC allows a processor to perform high-order algorithmic calculations on the digital values that represent the analog signal. Without the digital values, it is very difficult to determine the actual

rain rate. In addition, the signal provided to the microprocessor will contain noise from non-rain vibrations, such as wind, engine vibrations, etc. The microprocessor of the '002 patent mistakenly utilizes the noise in calculating the intermittent period, leading to improper actuation of the wiper blade.

[0004] Another example of a sensing device of the prior art is disclosed in United States Patent No. 5,059,877. The '877 patent discloses a sensor block mounted on a windshield. The sensor block includes an array of light emitting diodes (LEDs) and an array of phototransistors. A control system that is associated with the sensor block includes an amplifier and a microcontroller. The microcontroller includes an ADC and a processor to determine the rain rate of rain striking the windshield. The '877 patent does not disclose the use of a piezoelectric vibration sensor to generate a signal when raindrops strike the windshield. A piezoelectric vibration sensor can detect vibrations anywhere on the windshield, not just in the limited area that is illuminated by the LEDs of the '877 patent.

[0005] Due to the deficiencies in the sensing devices of the prior art, there remains an opportunity to introduce a sensing device that is capable of calculating the rain rate using an equation derived from a point process equation. Very little filtering or signal conditioning of non-rainfall vibrations is needed to very accurately determine the rain rate in this fashion.

SUMMARY OF THE INVENTION AND ADVANTAGES

[0006] The invention provides a sensing device for determining a rain rate on a surface, such as a glazing of a vehicle. The sensing device enables a wiper blade to move across the glazing to remove raindrops from the glazing. The sensing

device includes a piezoelectric sensor, an amplifier, an analog-to-digital converter (ADC), and a processor. The piezoelectric sensor is mounted to the glazing and produces an analog signal proportional to vibrations caused by raindrops striking the glazing. The amplifier is electrically connected to the piezoelectric sensor for increasing an amplitude of the analog signal. The ADC is electrically connected to the amplifier for converting the analog signal into digital values. The processor is electrically connected to the ADC to receive the digital values. The processor computes the rain rate by using an equation derived from a point process equation.

[0007] The sensing device of the subject invention provides several advantages over the related art. One such advantage is the use of a point process, more specifically the use of a first order point process. The first order point process is also known, by those skilled in the art, as a Poisson process. Statistics of rainfall naturally exhibit the characteristics of a point process. Accordingly, the processor is capable of performing calculations using an equation derived from a point process equation to allow for a very accurate estimation of the rain rate. In addition, very little filtering or signal conditioning of non-rainfall vibrations is needed to determine the rain rate using the equation based on the point process equation. Of course, filtering may be added to reduce the amount of amplified noise in the analog signal.

[0008] The calculation of the rain rate inherently does not react to non-rainfall vibrations that may be present, since these non-rainfall vibrations do not exhibit the statistical characteristics of a point process. Examples of these non-rainfall vibrations include, but are not limited to, rocks hitting the vehicle, wind noise, and acoustical vibrations caused by speech or a vehicle's sound system.

BRIEF DESCRIPTION OF THE DRAWINGS

[0009] Other advantages of the present invention will be readily appreciated as the same becomes better understood by reference to the following detailed description when considered in connection with the accompanying drawings wherein:

[0010] Figure 1 is a perspective view of a vehicle incorporating a sensing device according to the subject invention;

[0011] Figure 2 is schematic block diagram of the sensing device;

[0012] Figure 3a is a cross-sectional view of a glazing, illustrating the piezoelectric sensor disposed between a first glazing pane and a second glazing pane; and

[0013] Figure 3b is a cross-sectional view of the glazing, showing the sensing device attached to the glazing.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

[0014] Referring to the Figures, wherein like numerals indicate like or corresponding parts throughout the several views, a sensing device is generally shown at **10**. The sensing device **10** of the subject invention includes the ability to determine a rain rate of rain striking a surface **26**.

[0015] Referring to Figure 1, the vehicle **12** includes a vehicle glazing **14** and at least one wiper blade **16**. Preferably, as disclosed in Figure 1, two wiper blades **16** are utilized. The wiper blades **16** move across the glazing **14** to remove raindrops from the glazing **14**. Those skilled in the art appreciate that the glazing **14**

of a vehicle may include, but is not limited to, a windshield, a back window, or a side window of a vehicle.

[0016] Referring now to Figure 2, at least one motor **18** is operatively connected to the wiper blades **16** for moving the wiper blades **16** across the glazing **14**. Preferably, only one motor **18** is needed for the two wiper blades **16**. At least one switch **20** is operatively connected to the motor **18** for activating the motor **18**. Preferably, only one switch **20** is necessary for the one motor **18**. However, it is to be understood, that the wiper blades **16**, motor **18**, and switch **20** can be configured differently without varying the scope of the subject invention.

[0017] A controller **22** is operatively connected to the switch **20**. The controller **22** activates the switch **20**, which in turn activates the motor **18**, which then causes the wiper blades **16** to move across the glazing **14** and remove the raindrops from the glazing **14**.

[0018] The sensing device includes a piezoelectric sensor **24**. Referring again to Figure 1, the piezoelectric sensor is mounted to a surface **26** of the vehicle **12**. It is preferred that the piezoelectric sensor **24** is mounted to the glazing **14**, therefore described below only in terms of the glazing **14** being the surface **26**. However, it is to be understood that in alternative embodiments, the piezoelectric sensor **24** can be mounted to a roof **30**, or hood **32** of the vehicle, etc. It is to be understood that different vibration characteristics of the vehicle **12** occur at different locations on the vehicle **12**. Hence, additional provisions, such as filtering or absorption, may be necessary depending on a mounting location for and properties of the piezoelectric sensor **24**. It is preferred that the piezoelectric sensor **12** is mounted

at a center line of the glazing **14**, however, other locations on the glazing are also acceptable.

[0019] Preferably, the piezoelectric sensor **24** is a high temperature thin film-type piezoelectric sensor. An example of a suitable piezoelectric sensor is a piezoelectric sensor that has properties such as a sensitivity of 5 mV/g, a measurement range of ±1000 g peak, and a frequency range of 0.01 to 10^9 Hz. However, other piezoelectric sensors are acceptable.

[0020] Referring again to Figure 2a, the piezoelectric sensor **24** produces an analog signal proportional to vibrations caused by the raindrops striking the glazing **14**. The analog signal produced by the piezoelectric sensor **24** has a very small amplitude, as seen by the sensitivity of the piezoelectric sensor **24**. This very small amplitude, in the millivolt range, cannot be useful when directly interfaced with standard microelectronic components that operate in the decivolt range. As a result, the sensing device **10** also includes an amplifier **34** that is electrically connected to the piezoelectric sensor **24**. The amplifier **34** increases the amplitude of the analog signal such that the analog signal can be utilized by other components.

[0021] The sensing device **10** further includes an analog-to-digital converter (ADC) **36** and a processor **38**. The ADC **36** is electrically connected to the amplifier **34**. The ADC **36** converts the analog signal into digital values. The processor **38** is electrically connected to the ADC **36** and the controller **22**.

[0022] The processor **38** computes a rain rate by using the digital values, provided by the ADC **36**, in an equation derived from a point process equation. The point process equation is further defined as an exponential probability density function of a first order point process and is represented by the equation f(t) =

$\lambda e^{-\lambda t}$, where f(t) represents a theoretical form of the first order point process, λ represents the rain rate, and t represents time values between raindrops striking the surface. The analog signal includes peaks that occur when the raindrops strike the surface. These peaks are encoded in the digital values. In order to calculate the rain rate λ, the processor **38** must be capable of determining the peaks encoded in the digital values. The processor **38** must also be capable of determining time intervals between the peaks. The time intervals between a first time and a second time that fall in a first range are summed by the processor **38**, creating a number n_1. The processor **38** must also sum a number n_2 of time intervals between the second time and a third time that fall in a second range.

[0023] A first embodiment requires that the processor **38** maintain the first range and the second range of time intervals equal in a time span w. The processor **38** must then be capable of determining an intermediate rain rate λ_{int} using the equation $\lambda_{int} = -2\cdot(n_2 - n_1) / w\cdot(n_2 + n_1)$. Next, the intermediate rain rate λ_{int} is successively determined by the processor. To conclude the first embodiment, the processor must be capable of averaging the intermediate rain rates λ_{int} to determine the rain rate λ.

[0024] In a second embodiment, the first range of time intervals is further defined as all time intervals less than or equal to the second time. The second range of the time intervals is further defined as all time intervals greater than the second time. To determine the rain rate λ using the second embodiment, the processor must be capable of calculating an equation $\lambda = n_1 / n_2$.

[0025] A third embodiment is similar to the second embodiment. However, the third embodiment provides a more accurate determination of the rain

rate λ than the second embodiment. The first range of time intervals is further defined as all time intervals less than or equal to the second time. The second range of the time intervals is further defined as all time intervals greater than the second time. To determine the rain rate λ using the third embodiment, the processor must be capable of calculating an equation $\lambda = n_1 / (T * n_2)$, where T represents the second time.

[0026] Once the rain rate λ is determined, the processor **38** then provides the computed rain rate to the controller **22**. The controller **22** automatically operates the wiper blades **16** to remove raindrops from the glazing **14** based on the rain rate.

[0027] In an alternative embodiment, as shown in Figure 2b, the ADC **36** and the processor **38** are incorporated into a single microcontroller **40**. In this embodiment, the microcontroller **40** is electrically connected to the amplifier **34** and the controller **22**. An example of a suitable microcontroller **40** is the PIC12C672 manufactured by Microchip Technology Inc. of Chandler, Arizona. This particular microcontroller has a RISC architecture and a 8-bit ADC, operates at 4 MHz with an internal oscillator or 10 MHz with an external oscillator, can perform one single cycle instruction every 400 ns, and includes 128 bytes of data RAM and 2048 bytes of Program EEPROM. Of course, as is evident to those skilled in the art, other suitable microcontrollers that meet these requirements are acceptable.

[0028] Referring now to Figure 2c, the sensing device **10** may also include a filter **42** to remove noise from the analog signal. The filter **42** is electrically connected to the amplifier **34** and the ADC **36**. The filter **42** is a band-pass filter to pass frequencies between approximately 4 kHz and approximately 8 kHz. Preferably,

the filter **42** is a standard fixed analog-type filter. However, other type of filters, such as a switched capacitive filter embodied in an integrated circuit, could also be used.

[0029] The sensing device may also include a flexible circuit board **44**. The flexible circuit board **44** supports and electrically connects the piezoelectric sensor **24**, the amplifier **34**, the ADC **36**, the filter **42**, and the processor **38**. It is known, to those skilled in the art, that flexible circuit boards are also termed flex circuits, flexible printed circuits, and the like. Flexible circuit boards can be bent, twisted, and folded to fit into space restrictive configurations.

[0030] Referring to Figures 3a and 3b, the vehicle glazing **12** is further defined as a first glazing pane **36** and a second glazing pane **38**. The first and second glazing panes **36, 38** are preferably made of glass, however other substances, such as resin, can be used instead of glass. Typically, the first and second glazing panes **36, 38** are affixed together with a polymer adhesive **40**.

[0031] The flexible circuit board **44** may be mounted on or in the glazing **12** in a variety of locations. In one embodiment, as disclosed in Figure 3a, the piezoelectric sensor **24** is disposed between the first and second glazing panes **36, 38**. In another embodiment, disclosed in Figure 3b, the piezoelectric sensor **24** is affixed to the glazing **12**, either inside or outside of the vehicle **10**.

[0032] Obviously, many modifications and variations of the present invention are possible in light of the above teachings. The invention may be practiced otherwise than as specifically described within the scope of the appended claims.